Low uncertainty determined by modern approach for high precision optoelectronic phase noise measurements

Ekaterina Pavlyuchenko, Patrice Salzenstein

Low uncertainty determined by modern approach for high precision optoelectronic phase noise measurements

Ekaterina Pavlyuchenko and Patrice Salzenstein
Centre National de la Recherche Scientifique (CNRS), Institut Franche Comté Electronique Thermique Optique Sciences et Technologie (FEMTO-ST), Optics department, route de Gray, F25030 Besançon Cedex, France
Phone: +33381666419 Fax: +33381666423
patrice.salzenstein@femto-st.fr

Abstract: Uncertainty on phase noise is calculated by modern approach for an optoelectronic measurement system. The final global uncertainty on the spectral density of phase noise determined by this method is lower than 2 dB.

1. Introduction

Optoelectronic oscillators (OEO) with high quality factor (Q-factor) resonators present a great interest for several applications in metrology, fundamental physics or telecommunication. These applications require that the OEO deliver an ultra stable signal [1–3]. The resonance frequency of such an oscillator is rarely predictable because it depends inherently on physical or geometrical parameters of the resonator. That's why the measurement of phase noise is not obvious to implement. A new category of instruments specially dedicated to the measurement of phase noise has been developed to determine the phase noise for any delivered signal in X-band (8.2–12.4 GHz). After a brief presentation of the main principle, we detail how the uncertainty is determined by a modern method.

2. Main principle of high precision optoelectronic phase noise measurements

In this system, the oscillator frequency fluctuation is converted to phase frequency fluctuation through the delay line. Short-term instabilities of signal are characterized in terms of single sideband noise spectral density $S_\varphi(f)$ in dB.rad²/Hz or rather £(f) expressed in dBc/Hz. $|H_\varphi(jf)|^2 = 4.\sin^2(\pi f\tau)$ is the transfer function of optical delay line, f is the offset frequency from the microwave carrier, τ is the delay related to optic fibers [4]. The phase noise in dBc/Hz of the OEO to be characterized is defined by Eq. (1) **:**

$$\pounds(f)=[V^2_{out}(f)] \,/\, [2K^2_\varphi.|H_\varphi(jf)|^2 G^2_{DC}\, B] \qquad (1)$$

where V_{out} is the amplitude of the output signal, $\varphi(t)$ is the phase fluctuation, G_{DC} is the gain of DC amplifier, K_φ depends on the mixer, B is the bandwidth.

Equation (1) shows that the sensitivity of the system depends directly on K^2_φ and $|H_\varphi(jf)|$. In practice, we need a Fast Fourier Transform (FFT) analyzer to measure the spectral density of noise amplitude $V^2_{out}(f)/B$.

The background phase noise of the bench shown on Figure 1 is determined after averaging with cross-correlation method, when removing the optical delay lines. In this case, phase noise of the X-band synthesizer is rejected. The noise floor without optical transfer function is respectively then better than -150 and -170 dBc/Hz at 10^1 and 10^4 Hz from the 10 GHz carrier. When optical fiber is introduced noise floor of such a system is up to -90 and -170 dBc/Hz at 10^1 and 10^4 Hz from the 10 GHz carrier.

3. Modern approach to express the uncertainty

For the evaluation of the uncertainty, we use the main guideline [5] delivered by the *Bureau International des Poids et Mesures* (BIPM) in the guide "Evaluation of measurement data – Guide to the expression of uncertainty in measurement (GUM)". The ideas of error and uncertainty were mixed up until the GUM clarified their meanings [6]. Thanks to our experience on similar issues, we must take into account all contributions and assess their weight in the determination of the uncertainty [7,8]. However, taking into account certain characteristics due to optics, the result is significantly different from the conventional method [9,10]. According to the guideline, the uncertainty in the result of a measurement generally consists of several components which may be grouped into two categories according to the way in which their numerical value is estimated. The first category is called "type A", is those which are evaluated by statistical methods such as reproducibility, repeatability, special consideration about Fast Fourier Transform analysis, and the experimental standard deviation. The components in category A are characterized by the estimated variances. Second family of uncertainties contributions is for those which are evaluated by other mean. They are called "type B" and due to various components and temperature control. Experience with or general knowledge of the behavior and properties of relevant materials and instruments, manufacturer's specifications, data provided in calibration and other certificates, uncertainties assigned to reference data taken from handbooks. The components in category B should be characterized by quantities which may be considered as approximations to the corresponding variances.

4. Conclusion

By taking into account the contributions mentioned above, the accuracy of determining the 2 dB overall uncertainty is improved.

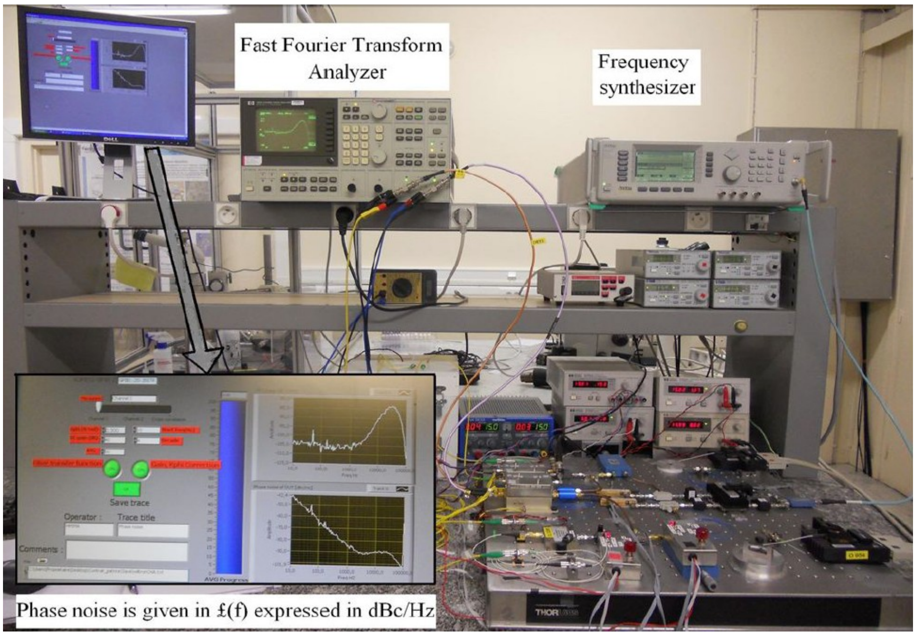

Fig. 1. High precision optoelectronic phase noise measurement system. It is dedicated to optoelectronic oscillators characterization.

5. References

[1] D. Eliyahu et al., "Phase noise of a high performance OEO and an ultra low noise floor cross-correlation microwave photonic homodyne system," IEEE Freq. Contr. Symp., Honolulu, may 2008, pp. 811–814 (2008).
[2] K. Volyanskiy et al., "Compact Optoelectronic Microwave Oscillators using Ultra-High Q Whispering Gallery Mode Disk-Resonators and Phase Modulation," Opt. Express **18**(21), 22358–22363 (2010).
[3] P. Salzenstein et al., "Investigation in acousto-optic laser stabilization for crystal resonator based optoelectronic oscillators," Opt. Eng. **52**(2), 024603 (2013).
[4] P. Salzenstein et al., "Realization of a Phase Noise Measurement Bench Using Cross Correlation and Double Optical Delay Line," Acta Phys. Pol. A **112**(5), 1107–1111 (2007).
[5] GUM: Guide to the Expression of Uncertainty in Measurement, fundamental reference document (2008). http://www.bipm.org/en/publications/guides/gum.html
[6] R. Kacker et al., "Evolution of modern approaches to express uncertainty in measurement," Metrologia **44**(6), 513–529 (2007).
[7] P. Salzenstein et al., "Frequency stability measurements of ultra-stable BVA resonators and oscillators", Electron. Lett. **46**(10), 686-688 (2010).
[8] P. Salzenstein et al., "Distributed amplified ultra-stable signal quartz oscillator based," Measurement **45**(7), 1937–1939 (2012).
[9] P. Salzenstein et al., "Estimation of the uncertainty for a phase noise optoelectronic metrology system", Phys. Scrip. **2012**(T149) 014025 (2012).
[10] W.K. Lee et al., "The uncertainty associated with the weighted mean frequency of a phase-stabilized signal with white phase noise," Metrologia **47**(1), 24–32 (2010).